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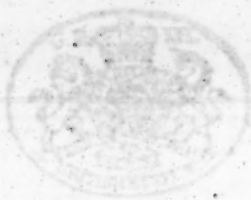
Dividing ASTRONOMICAL INSTRUMENTS.

By Mr. JOHN BIRD,
MATHEMATICAL INSTRUMENT-MAKER, in
the STRAND.

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MDCCLXVII.



P R E F A C E.

MR. John Bird, Mathematical Instrument-maker, in the Strand, having received the sum of 500 *l.* by certificate from the Commissioners of Longitude, upon the following, amongst other, conditions; namely, of taking an apprentice for seven years, and instructing him in his art and method of making Astronomical Instruments; and also in instructing, in like manner, such other persons as the said Commissioners shall from time to time direct: And further, of giving and delivering in Writing, upon Oath, to the said Commissioners, a full and complete description of his manner and method of forming and graduating Astronomical Instruments, and particularly all such as he hath made for the use of the Royal Observatory at Greenwich: And he having further agreed to give and deliver in, upon oath, to the said Commissioners, complete engraved Plates of the said last-mentioned Instruments, so minutely exact, as that these
 Plates,

Plates, with the aforesaid Description, and Models thereof, if necessary, may enable any diligent and experienced Workman to make and execute such Instruments, for which Plates he is to be allowed the further sum of 60*l.* the said Mr. John Bird accordingly delivered the following Writing, with the engraved Plate, N^o. 4, therein referred to, to the Commissioners of Longitude, March 21, 1767, upon oath, as containing a true description of his manner of dividing the Mural Arc in the Royal Observatory; together with the improvements which he has made, since the construction thereof, in his method of dividing Instruments.

The Commissioners thought proper to order this Account to be printed and published immediately, which will doubtless be followed by the other Part of the Method, relative to the Construction of Astronomical Instruments, promised by Mr. Bird, when he shall have completed the same.

N. MASKELYNE,
Astronomer-Royal.

T H E

T H E A U T H O R ' s
P R E F A C E.

THE following Method of dividing Astronomical Instruments, &c. is collected principally from the experience which I have gained in the space of thirty-four years, and, in some part, from the instructions which I received from the late Mr. Jonathan Sisson.

What I call my own, I have distinguished by Italic characters: If any other Instrument-makers have used the same method, it is unknown to me; and shall, therefore, pay no regard to any pretensions unsupported by evidence: I mean, pretensions, without producing Astronomical Instruments superiour, or at least equal to, those which I have made.

How far the Lunar Theory hath been improved by the observations of the late Dr. Bradley, and Mr.
B
Mayer,

Mayer, I leave to the decision of those who have tried it by observations, in order to find the Longitude at sea, &c. I cannot help, however, being fully of opinion, that a still more perfect knowledge of the motion of the heavenly bodies may be obtained by future observations, ~~skilfully~~ made, with accurate Instruments.

I have been favoured with so distinguished a mark of approbation, from the Commissioners of Longitude, that nothing, on my part, shall be wanting, that may in the least contribute to so desirable an end.

J O H N B I R D.

March 14th,
1767.

T H E
M E T H O D
O F

Dividing ASTRONOMICAL INSTRUMENTS.

AT a Board of Longitude, held at the Admiralty on the 10th of January, 1767, it was required of me to describe my method of dividing Astronomical Instruments, and the said description to be delivered at a subsequent Board, to be held on the 14th of March following.

As this is, in some measure, defeating my intention, which was to describe the regular process, used in making the Mural Arc of 8 feet Radius in the Royal Observatory at Greenwich, I shall describe the method used in dividing the said Instrument; that it may be a proper supplement to a description thereof, which I hope to perfect, some time in the following Summer.

It will be sufficient, for my purpose, to make use of no more Lines and Arcs than are represented in the Figure C B A, Plate 4.

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The requisites for the performance of this work are as follow. A scale of equal parts, by which the Radius may be measured to 0,001 of an inch, must be provided. My scale is 90 inches long, each inch divided into 10, contiguous to which are nonius divisions, viz. 10,1 inches divided into 100 equal parts, shewing 0,001 of an inch; and by the assistance of a magnifying glass, of one inch focal length, a third of 0,001 may be taken off by estimation.

Provide five Beam Compasses, to which magnifying glasses, of not more than one inch focal length, should be applied. Let the longest beam be sufficient to draw the Arcs, and measure the Radius: The 2d to measure the Chord of $42^{\circ}:40'$: The 3d to measure the Chord of 30° : The 4th $10^{\circ}:20'$: The 5th $4^{\circ}:40'$: And, if a 6th, to measure 15° , be made use of, so much the better.

I have, for the sake of a round number, mentioned above, that the Radius of the Mural Arc, in the Royal Observatory at Greenwich, is 8 feet; but, as I shall here put down the lengths of the several Chords made use of in the dividing, it will be necessary to note the exact Radius in inches and decimal parts.

The Radius of the Arc of 90° , at the points, = 95,938 inches, from which the following numbers were computed, viz. 49,6615 inches = Chord of 30° — 25,0448 inches = Chord of 15° — 17,679047 inches = Chord of $10^{\circ}:20'$ — 7,81186 inches = Chord of $4^{\circ}:40'$ and 69,80318 inches = Chord of $42^{\circ}:40'$. Having drawn the several Arcs, between which the divisions were to be cut, the Radius and the lengths of the above Chords were taken by the Beam Compasses, which, together with the Scale, were laid upon the Quadrant,

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where

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where they remained till the next morning; during which time the door of the room was kept locked. Before sun-rise I remeasured the Radius, which required some correction; the Beam being of white fir, and the Scale of brass, which probably contracted, while the Beam remained unaltered: The other Beam Compasses also required correction.

Now the Quadrant and Scale being of the same temperature, the faint Arc $b d$ was struck, and with a very fine prick-punch the point a was made: With the same Beam Compass, unaltered, I laid off, from a to e , the Chord of 60° , making also a fine point: With the Chord of 30° , $a e$, was bisected in, c . Now one point of the Beam Compass, containing 60° , was fixed in, c ; and with the other was marked the point, r , or 90° : Next, with the Beam Compass, containing 15° , was bisected, er , in, n , or 75° : From, n , was laid off the Chord of $10^\circ : 20'$, and from, r , $4^\circ : 40'$; which two last Chords joined exactly in, g , being the point of $85^\circ : 20'$: Now each degree being to be divided into 12 parts, or every $5'$, therefore $85 \times 12 + 4 = 1024$, a number divisible by continual bisections. The last Chord computed was $42^\circ : 40'$, with which, ag , was bisected in, o ; ao , and, og , were bisected by trials: But whoever undertakes to divide a large Quadrant, will do well to compute also the Chord of $21^\circ : 20'$; but, for this Chord, any of the Beam Compasses already provided, which will take in the length, may be used. The point, g , being found as above, I proceeded, by continual bisections, till I had the number required, viz. 1024. To fill up the space between, g , and, r , containing 56 divisions, the Chord of 64 divisions was laid off from, g , towards, d , and divided, like the rest, by continual bisections; as was also from, a , towards, b . The points 30 , 60 , 75 , and 90° , fell in, without any sensible inequality.

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Here it is necessary to mention, in what manner the bisecting and pointing were performed. Having the Chord of $42^{\circ} : 40'$ in the Beam Compass, and one point placed in a , with the other a faint arch of about $\frac{1}{20}$ of an inch in length was made in o : Again, one point of the Beam Compass was placed in g , and with the other the aforefaid faint arch was intersected. Here, as in all other places, great care was used to make the points exactly in the arc to be divided, and also in the intersection.

In the following pages, I shall not only describe the farther process in dividing the Mural Arc in the Royal Observatory, but endeavour also to make the description general.

If the Chord should be taken a little too long, or too short, so that the intersection be made on one side or the other of the arc to be divided, it will not occasion an inequality, provided the point be made in the middle between the two short lines, *except at the point of $42^{\circ} : 40'$, where great care must be used in taking the Chords from the Scale. Great care must also be used in pointing intersections in general, being more difficult than a single line: But here I must not be understood to mean a single line, made by one point of the Compass; for, in all bisections, the place to be pointed must be laid off from left to right, and from right to left; and if any error arises, from an alteration of the Beam Compass, it will be shewn double.*

In dividing, the points of the Beam Compass should never be brought nearer together than 2 or 3 inches, except near the ends of the arch or line to be divided; and there spring-dividers, having round points, which may be put in and taken out occasionally, will best answer the purpose.

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The next thing to be considered is the method of making the points: The prick-punch, for this purpose, must be extremely sharp, and round, the conical point to make a pretty acute angle; and as the points, herewith to be made, *should not exceed 0,001 of an inch, when linear divisions are to be cut from them, a magnifying glass of $\frac{1}{2}$ inch focal length should be used*; by the assistance of which, the impression, or scratch, made by the points of the Beam Compass, will be very conspicuous; *and, if the said impression be not too faint, feeling, as well as seeing, will greatly contribute to make the points properly.*

It is scarce necessary to say any thing about the Arc of 96: I shall only mention, that it contains 1536 divisions; is to be divided into three equal parts, in the same manner as the Arc of 90°; each third contains 512 divisions, which number is divisible continually by 2, and gives 16 in each 96th part of the whole Arc.

This Arc of 96 (so far as I know) was first applied to the Iron Quadrant, in the Royal Observatory, in the year 1725, by my late worthy friend, Mr. Geo. Graham: It was not only a severe check upon that great mechanic, but will be so to all others, who divide the two arcs, upon one and the same instrument; yet, if the above instructions be strictly followed, the agreement between the two will be surprising, and differ very little from the truth.

The next step is to cut the linear divisions from the points: The best instrument for this purpose is the Beam Compass, *having both its points conical, and very sharp.* Draw a Tangent to the Arc *bd*, suppose at *e*, it will intersect the Arc *xy* in *q*;

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this will be the distance between the points of the Beam Compass, to cut the divisions (nearly) at right angles to the Arc *bd*.

Lodge that point of the Beam Compass next your right hand, in the point, r ; let the other fall freely into the Arc, $\times y$; press gently with your finger upon the screw-head, which fastens the socket [this screw-head must be convex, and right over the point]; and, with the point towards the right hand, cut the divisions.—In this manner you must proceed with the rest.

Having finished the divisions of the limb, the nonius divisions are next to be divided. Chuse any part of the arch, where there is a coincidence of the 90 and 96 arches, which let be at e : Draw the faint arcs st and ik , which may be continued to any length towards A, upon which the nonius divisions must be divided, in points: A Tangent line, as before, intersecting this Arc, gives the distance of the points in the Beam Compass. Now, as the nonius divisions of the arc 90° subdivide the divisions of the limb of the Mural Arc at Greenwich to half a minute, 11 divisions of the limb being equal to 10 upon the nonius plate (a number which only 5 and 2 will divide), *recourse must again be had to computation. Measure the Radius of the Arc, and compute the Chord of 16, or rather 32, of the nonius divisions; the quantity of an Arc, equal thereto, may be easily had by the following proportion: As $10 : 55'$ (the number of minutes in 11 divisions of the limb) $:: 32 : 2^\circ : 56'$, the Chord of which must be computed, and taken from the scale of equal parts: But, as different subdivisions by the Nonius may be required, let n = number of nonius divisions, m = number of minutes taken in*
by

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by the Nonius, $b = 16, 32$ or 64 , and $x = \text{Arc sought}$; then as $n : m :: b : x$.

Lay off with the Beam Compass, having the length of the Tangent between the points, the point, q, from, e, and the Chord of 32 from, q, towards the left hand, and divide by continual bisections, 10 of those divisions, counting from, q, to the left, will be the points required. As the number of nonius divisions for the 96 Arch should always be 16, 32, &c. I need only mention, that the extremes may be laid off from the divisions of the limb, without computation.

Now the place upon the chamfered edge of the nonius plate, where the Nonius is to begin, may be found in the following manner. *Measure the distance of the Quadrant's center, from the axis of the Telescope; this distance from the axis of the Telescope at the eye-end, will be the place for the first division of the Nonius, where draw a faint line from the center. The greater accuracy with which this is laid off, the nearer to the axis of the tube will be the intersection of the wires, in the common focus of the object and eye-glasses.*

I will suppose, that no Instrument-maker will fix to the Telescope, the Nonius, and center-plates, without steady-pins, as well as screws. Screw the center-plate of the Telescope very fast: Put the nonius plate upon the steady-pins, without screws, and put the Telescope upon the Quadrant: Make fast the nonius plate to the arch with two pair of hand-vices, and take the Telescope away. *Now, with one point of a Beam Compass, in the center of the Quadrant, and the other at the middle of the nonius plate, draw a faint arch from end to end: Where this arch cuts the*

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faint

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faint line, before mentioned, make a fine point: From this point lay off on each side another, which may be at any distance in the arch; only care must be taken, that they be equally distant from the middle point: From the two last make a faint intersection, as near as possible to either of the chamfered edges of the nonius plate: Through this intersection, the first division of the Nonius must be cut.

Put the Telescope again upon the center of the Quadrant, the steady-pins into the nonius plate, as before; unscrew the hand-vices, and bring the last mentioned intersection to e , or 60° upon the limb, where fasten it again with the hand-vices, and take away the Telescope. Now, from the points before divided, the nonius divisions must be cut; by lodging the left hand point of the Beam Compass in the points upon the arch, and cutting with the right.

Here great care must be taken, to cut the first division of the Nonius through the point of *intersection*; which may be done by altering the distance of the points in the Beam Compass, if necessary: This will not sensibly affect the perpendicularity of the divisions, provided the intersection be placed very near to e , or 60° .

Having cut the nonius divisions, suppose, of the 90 arc, take up the plate, polish off the burr, and fasten it to the limb, as before; but here great care must be taken to make the first division of the Nonius coincide with the 60th deg. so as to appear one line; and the Nonius of the 96 arc may be cut in the same manner, making the first division coincide with $64 = 60^\circ$ upon the limb.

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Now take up the plate, and draw a Tangent at the point in the faint arc in the middle of the nonius plate; and, with a distance about a quarter of an inch longer than the Nonius, lay off from the Tangent point another in the Tangent line; also lay off this distance from the centre of the collar at the object end of the Telescope, and make a fine point: Then extend the Beam Compass nearly the whole length of the Nonius, or center plate (which should reach, at least, half an inch beyond the Telescope on the contrary side), and lay off other points in the Tangent line before mentioned, and in a line passing through the center of the Quadrant, at right angles to the Telescope.

Now screw the two plates to the Telescope, and draw lines by the edge of a steel-ruler, through the correspondent points, to which lines the plates must be carefully filed: Then the ends of the plates will be in lines parallel to each other, and to the axis of the tube, which affords an excellent mechanical method of finding the line of collimation of the Telescope.

The apparatus used, for this purpose, by the late Mr. Graham, was a box equal in length to the Telescope, having deep sides, to prevent its bending by its own weight: The ends were of hard wood; *instead of which, I use two flat pieces of brass, which I can move according to different lengths required; and, by the help of a small spirit Level, these pieces of brass may be fixed in one and the same plane.* This apparatus should stand firm upon the ground, where a distant and distinct object can be seen: Rest the ends of the Nonius and Center Plates upon the two pieces of brass, and observe what

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what point of the object is cut at the intersection of the horizontal and vertical wires:—Invert the Telescope; and, if the horizontal wire does not cut the same point of the object, it must be altered, by the screws for that purpose, half the difference. By repeating this, you may approximate extremely near the truth.

In the middle, between the 90 and 96 arches of the Mural Quadrant, in the Royal Observatory, is an arch of points (96), which are used with a silver wire, of about 600 in an inch, carried by a small frame, screwed to the end of the Nonius Plate: When the wire, in an observation, falls between two points, it must, by the Micrometer Screw, be made to bisect the nearest point to the left hand*; and the minutes and seconds, shewn by the Micrometer, added: If the next point to the right hand be bisected, the minutes and seconds must be subtracted.—This arch of points was divided, in every respect, like the other arch of 96.

Having gone through the whole process of dividing the Mural Arc, &c. it will be necessary to shew some reasons why this kind of management hath succeeded better than any other, as far as I either know or have heard.

After I had found, by experience, that the expansion of the Instruments to be divided, occasioned by the increasing heat of the sun, or a contraction, by a decrease thereof, was the grand difficulty with which I had to struggle, especially when two or three

* The Instrument shewing the Zenith distance.

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hours were required to lay off the principal points; I immediately set about contriving how to lay them off, in the least time possible, i. e. before any expansion, or contraction, could take place; and, as the heat of three or four persons in the room may produce the same effect as the sun, I never admit more than one, as an assistant: Neither must any fire be suffered in the room, till the principal points are done.

The above being understood, it was easy to conceive, that, having all the Chords before mentioned computed, and measured, the evening before they were to be laid off, I should be enabled to perform in a few minutes, what by trials would require some hours; and, as too much caution cannot be used, it is proper to lay off the principal points before sun-rise, or else chuse a cloudy morning.

The method of cutting the divisions, as described above, is to prevent any inequality that would arise from the expansion of the Beam Compass by the heat of the hands, especially if the Beam be of metal: Wooden Beams will also alter, probably from a small bending; but in this method, if the Beam should alter $\frac{1}{10}$ of an inch, or more, it would not cause any sensible inequality.

As the points of the nonius divisions cannot be divided upon the nonius plate, without inconvenience, it is best to use the method described in page [8], holding the Beam Compass a small while in the hand, previous to the cutting. The points being but few in number, the divisions may be cut, before any expansion can sensibly take effect.

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Sextants, or Octants, for observing the distance of the moon from the fixed stars, should be divided by the foregoing method, great accuracy being required. *If, instead of dividing Sextants to every 20' upon the limb, as is commonly done, they should be divided to 15', a Chord of 64° might be laid off, and divided by continual bisections:* This would, in some measure, crowd the Limb with divisions; but it would shorten the Nonius; for 15, instead of 20, would shew one minute.

In dividing either Arches or Strait Lines, a number (which will divide continually by 2) greater than is required upon the Arc or Line, is the best to begin with, and may be used in dividing a Circle, by laying off the Chord of the difference: Suppose it was required to divide a Circle into 54 equal parts, it would be $64 - 54 = 10 = 10^\circ : 30'$; the Chord of which, laid off, must be added to 360° , and it will be $360^\circ + 10^\circ : 30'$, to be divided into 64 equal parts, 54 of which will complete the Circle.—If the Arc of $10^\circ : 30'$ be laid off from a dividing plate, it will answer the same purpose.

Analagous to the foregoing method, my scale of equal parts was divided. I took $\frac{5 \frac{1}{2}}{16}$ of an inch in a Beam Compass, laid the Scale which I took it from, the Brass Scale to be divided, and the Beam Compass, in a room facing the North, where they lay the whole night: Early next morning, after correcting the lengths, the above $\frac{5 \frac{1}{2}}{16}$ were laid off three times (the Brass being long enough to take it in); then, having in other Compasses 256, 128, and 64, I bisected the three spaces of 512 with all the expedition I could: Having now only 6,4 inches in the last Beam Compass, any partial or unequal expansion was not to be

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be feared; therefore worked by continual bisections, till I had done. *The linear divisions were cut from the points, with a Beam Compass, as before described.*

The nonius divisions of this Scale contain $\frac{1.01}{100}$ of an inch, which were divided into 100 in the following manner. *As 100 : 101 : 256 : 258,56 tenths of an inch, the integer in this case being $\frac{1}{100}$. Suppose the Scale to be numbered at every inch, from left to right; then exactly against $\frac{1}{100}$, to the left of 0, was made a fine point; from which was laid off 258,56 to the right hand.*——This was taken from a Scale 3 feet in length, which was divided after the common method; but the error was so small, as to vanish at the other extremity of the Nonius, when divided continually by 2.

Whoever undertakes to divide a Scale of the above kind, not being furnished with one long enough to lay off 258,56 *may take $\frac{2.58}{100}$ from that before him, to which he may add 8,56 taken from a diagonal Scale, that may be made at a small expence.*

To prove the expedience of the above methods of dividing Astronomical Instruments, &c. I need only to mention the following particulars, taken from the Nautical Almanac for this present year 1767, page 152.

“ Mr. Mayer made his observations with his six-foot Mural
 “ Arch, from the year 1756 to the time of his decease: With
 “ it he settled the mean obliquity of the Ecliptic, to the begin-
 “ ning of the year 1756, at $23^{\circ} : 28' : 16''$; which Dr. Bradley
 “ settled

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“ settled by his observations, made in the years 1750 and 1751,
 “ at $23^{\circ} : 28' : 18''$. The difference is agreeable to what ought
 “ to arise from the gradual diminution of the obliquity of the
 “ Ecliptic, at the rate of about $\frac{1}{2}$ a second in a year,” &c. That
 two different observers, with instruments of different radii, and
 in different parts of Europe, should so nearly agree, is matter of
 no small astonishment; and sufficiently proves, that a mean of
 several observations, made by good observers with accurate in-
 struments, properly adjusted, will always lead us either to the
 truth itself, or extremely near to it.

JOHN BIRD.



